Chapter 6
Sewer Cleaning

Introduction
As stated, the deposition of sewage solids during dry weather in combined sewers has long been recognized as a major contributor to "first-flush" phenomena. Another manifestation of “first-flush,” in addition to the scouring of materials already deposited in the sewers, is the mobilization of loose solids on the urban ground surface and transported into the sewerage system by surface storm runoff. These particulates may settle out in the system and be scoured and resuspended during wet weather periods. Such materials also create “first-flush” loading from storm drainage systems. Deposition of heavy solids is also a problem in separate sanitary systems.

One underlying reason for considerable sewage solids deposition in combined sewers is the hydraulic design. Combined sewers are sized to convey many times the anticipated peak dry weather sewage flow. Combined sewer laterals can carry up to 1000 times the expected background sewage flow. Ratios of peak to average dry weather flow usually range from 2 to 10 for interceptor sewers. The oversized combined sewer pipes possess substantial sedimentation potential during dry weather periods. Dry weather flow velocities are typically inadequate to maintain settleable solids in suspension which tend to accumulate in the pipes. During rainstorms, the accumulated solids can resuspend and overflow to receiving waters.

Generally, if sediments are left to accumulate in pipes, hydraulic restrictions can result in blockages in flowline discontinuities. Otherwise, the bed level reaches an equilibrium level. A number of conventional cleaning techniques are described below, followed by a discussion of various manual and automated flushing methods.

Conventional Sewer Cleaning Techniques
Conventional sewer cleaning techniques include rodding, balling, flushing, poly pigs and bucket machines. These methods are used to clear blockages once they have formed, but also serve as preventative maintenance tools to reduce future problems. With the exception of flushing these methods are generally used in a "reactive" mode to prevent or clear up hydraulic restrictions. As a control concept, flushing of sewers is viewed as a means to reduce hydraulic restriction problems as well as a pollution prevention approach.

Power Rodding
Power rodding includes an engine driven unit, steel rods and a variety of cleaning and driving units. The power

equipment applies torque to the rod as it is pushed through the line, rotating the cleaning device attached to the lead end. Power rodders can be used for routine preventative maintenance, cutting roots and breaking up grease deposits. Power rodders are efficient in lines up to 0.30 m (12 in.) in diameter.

Balling
Balling is a hydraulic cleaning method in which the pressure of a water head creates high velocity water flow around an inflated rubber cleaning ball. The ball has an outside spiral thread and swivel connection that causes it to spin, resulting in a scrubbing action of the water along the pipe. Balls remove settled grit and grease buildup inside the line. This technique is useful for sewers up to 0.60 m (24 in.) in diameter.

Jetting
Jetting is a hydraulic cleaning method that removes grease buildup and debris by directing high velocities of water against the pipe walls at various angles. The basic jetting machine equipment is usually mounted on a truck or trailer. It consists of water supply tank of at least 3.8 m^3 (1,000 gal), a high pressure water pump, an auxiliary engine, a powered drum reel holding at least 152 m (500 ft) of 1 in. hose on a reel having speed and direction controls and a variety of nozzles. Jetting is efficient for routine cleaning of small diameter low flow sewers.

Pigging
Poly pigs, kites, and bags are used in a similar manner as balls. The rigid rims of bags and kites cause the scouring action. Water pressure moves these devices against the tension of restraining lines. The shape of the devices creates a forward jet of water. The poly pig is used for large sanitary sewers and is not restrained by a line, but moves through the pipe segment with water pressure buildup behind it.

Power Bucket
The power bucket machine is a mechanical cleaning device effective in partially removing large deposits of silt, sand, gravel, and grit. These machines are used mainly to remove debris from a break or an accumulation that cannot be cleared by hydraulic methods. In cases where the line is so completely plugged that a cable cannot be threaded between manholes, the bucket machine cannot be used. The bucket machine is usually trailer or truck mounted and consists mainly a cable storage drum coupled with an engine with controllable drive train, up to 300 m (1000 ft) of 1.3 cm (1/2 in.) steel cable and various sized buckets and tools. The cable drum and engine are mounted on a framework that includes a 1 m (36 in.) vertical A-frame high enough to permit lifting the cleaning bucket above ground level. Typically two machines of the same design are required. One machine at the upstream manhole is used to thread the cable from manhole to manhole. The other machine is used at the downstream manhole has a small swing boom or arm attached to the top of the A-frame for emptying cylindrical buckets. The bottom of the bucket has two opposing hinged jaws. When the bucket is plugged through the material obstructing the line, these jaws are open and dig into and scrape off the material and fill the bucket. When the bucket is pulled in the reverse direction, the jaws are forced closed by a slide action. Any material in the bucket is retained as the bucket is pulled out through the manhole.

Silt Traps
Silt traps (or grit sumps) have successfully been used to collect sewer sediments at convenient locations within the system with the traps being periodically emptied as part of a planned maintenance program. The design and operational performance of two experimental rectangular (plan) shaped silt traps in French sewer systems was reported (Bertrand-Krajewsk et al., 1996). Information on design procedures and methodology for silt traps is scarce.

Sewer Flushing Systems
Flushing of sewers either by manual or by automated means is generally meant to reduce hydraulic restriction problems and infrequently as a pollution prevention approach. Flushing of sewers has been a concern dating back to the Romans. Ogden (1892) describes early historical efforts for cleaning sewers in Syracuse, New York at the

turn of the century. The concept of sewer flushing is to induce an unsteady waveform by either rapidly adding external water or creating a "dam break" effect by quick opening of a restraining gate. Cleansing efficiency of periodic flush waves depends on flush volume, flush discharge rate, sewer slope, sewer length, sewer flow rate, sewer diameter and population density. Maximum flushing volumes at upstream points are limited by available space, hydraulic limitations and costs. Maximum flushing rates at the downstream point are limited by the regulator/interceptor capacities prior to overflow.

The relationship between cleaning efficiency and pipe length is important. The goal of flushing is to wash the resuspended sediment to strategic locations (i.e., to a point where the waste stream is flowing with sufficient velocity, to another point where flushing will be initiated, to a storage sump that will allow later removal of the stored contents, or to the wastewater treatment plant). This reduces the amount of solids resuspended during storm events, lessens the need for CSO treatment and sludge removal at downstream storage facilities, and allows the conveyance of more flow to the WWTP or to the drainage outlet. Clean sewers provide maximum wastewater carrying capacity thereby preventing sewer overflows and protecting the environment. There is another benefit to be gained by maintaining sewers in a clean and free flowing condition—sulfide odor and corrosion reduction.

Manual flushing methods usually involve discharge from a fire hydrant or quick opening valve from tank truck to introduce a heavy flow of water into the line at a manhole. Flushing removes floatables and some sand and grit, but is not very effective for removing heavy solids. In recent years, automated flushing equipment has emerged in France and Germany.

Hydrass®

The Hydrass® flushing system developed in France, and shown in Figure 3, is comprised of a balanced hinged gate with the same shape of the cross section of the sewer. At low flows the self-weight of the gate holds the gate in the vertical position and the sewer flow builds up behind the gate. The depth of flow continues to build up behind the gate until the force created by the retained water becomes sufficient to tilt the gate. As the gate pivots about the hinge to a near horizontal position, the sewer flow is released and this creates a flush wave that travels downstream and subsequently cleans any deposited sediment from the invert of the sewer. The gate then returns to the vertical position and the cyclic process is repeated, thus maintaining the sewer free of sediment. Gates are positioned in series at intervals dictated by the nature, magnitude and location of the sedimentation problem. Chebbo et al. (1995) reported the effective operation of the Hydrass system. This system has been installed on a segment of the Marseilles Number 13 trunk. A 100 m (328 ft) stretch required about 700 flushes to clean an initial deposit of about 100 mm (4 in.). Flushing frequency can be reduced if the upstream head can be increased. For example, the number of flushes with a 0.5 m (1.6 ft) head is 24 times more than that required for a 1.5 m (4.9 ft) head.

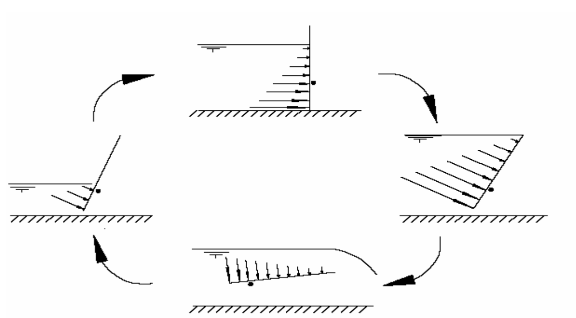

Figure 3. The Sequence of Hydrass® Sewer Flushing Gate Operates

Hydroself®

In recent years pollution caused by CSO has become a serious environmental concern. Over 13,000 CSO tanks have been constructed with over 500 being in-line pipe storage tanks 1.8 to 2.1 m (6 to 7 ft) diameter with lengths 125 to 180 m (400 to 600 ft). Discharge throttles control the outlet discharge to about twice the average dry weather flow plus infiltration. Many different methods for cleaning these pipes were tried over the years. One of the most popular flushing systems has been the Hydroself® system was developed by Steinhardt Wassertechnik, Taunusstein about 11 years ago (Pisano et al., 1997).

The Hydroself® system is a simple method that uses a wash water storage area and hydraulically operated flap gates to create a cleaning wave to scour inverts of sewers. This system consists of a hydraulically operated flap gate, a flush water storage area created by the erection of a concrete wall section, a float or pump to supply hydraulic pressure and valves controlled by either a float system or an electronic control panel. The water level in the sewer is used to activate the release and/or closure of the gate using a permanently sealed float controlled hydraulic system. The flushing system is designed to operate automatically whenever the in-system water level reached a pre-determined level, thereby releasing the gate and causing a "dam break" flushing wave to occur. Activation by remote control is also possible. This technology does not require an outside water supply, can be easily retrofitted in existing installations with a minimal loss of storage space, and may operate without any external energy source. The system consists of a hydraulically operated flap gate, a flush water storage area created by the erection of a concrete wall section, a float or pump to supply hydraulic pressure and valves controlled by either a float system or an electronic control panel. The actual arrangement for a given installation is site dependent. The sewer size, length, and slope determine the flush water volume needed for an effective single flush of the system.

The Hydroself® system has been used to clean settled debris in sewers, interceptors, tunnels, retention and detention tanks in Germany and Switzerland. This technology was first used in 1986 for cleaning a tank in Bad Marienberg (a small town with a population less than 10,000 people, about 100 km northeast of Frankfurt). In that same year the first two pipe storage projects, using the flushing gate technology, were implemented. This system has been used extensively in Europe with 284 installations with over 600 units in operation. Approximately 37% of the projects are designed to flush sewers, interceptors and tunnels ranging from 0.25 m to 4.3 m (0.8 to 14 ft) in diameter and flushing lengths of up to 340 m (1100 ft) for large diameter pipes and up to 1000 m (3300 ft) for small diameter pipes. The balance of flushing gate installations is for cleaning sediments from CSO tanks. The largest project in Paris, France cleans an underground 120,000 m^3 (31.6 Mgal) tank beneath a soccer field using 43 flushing gates (Pisano et al., 1997).

For large diameter sewers greater than 2 m (78 in.) the flushing system may be installed in the sewer pipe itself. The required storage volume for the flush water is created by erecting two walls in the sewer pipe to form a flush water storage area in between the two walls. For the area to remain free of debris, a reasonable floor slope (5 to 20%) must be provided in the storage area. The requirements for the storage area slope will determine, in most instances, the maximum flushing length possible for a single flush gate. Should the actual flushing length be longer than this value, then additional flushing gates must be installed to operate in series with the first one. In order to increase the maximum flushing length it is also possible to build additional flush water storage area by creating a rectangular chamber in-line or adjacent to the sewer line itself.

Biogest®Vacuum Flushing System

Biogest® is a system comprised of a concrete storage vault and a vacuum pump system to create a cleaning wave to scour the inverts of sewers. The system consists of a flush water storage area, diaphragm valve, vacuum pump, level switches, and a control panel for automatic operation of the system. The water level in the sewer is used to activate the vacuum pump. The vacuum pump evacuates the air volume from the flush chamber and as the air is evacuated the water is drawn in from the sewer and rises in the chamber. The vacuum pump shuts off when a predetermined level in the flushing vault is reached. A second level sensor detects the water level in the sewer and activates the flush wave. The flush wave is initiated by opening the diaphragm valve above the flush chamber and subsequently releasing the vacuum and vault contents (Pisano et al., 1997).

U.S. EPA Automatic Vacuum Flushing System

A new design of sediment flushing system was developed by the U.S. EPA (2003). The system includes a flushing-water reservoir that can be installed in either a CSO storage tank or in a combined sewer. The reservoir has an ingress-egress port through which WWF is received from and discharged and an air release valve that closes when the reservoir is substantially full to create a water-retaining vacuum. As the system surge passes and the water level falls, the vacuum seal is broken as air enters the reservoir through an air intake conduit, releasing the water from the reservoir to flush accumulated sediment solids from the storage tank or combined sewer. The reservoir defines a box-like receptacle having a top portion and downwardly-extending sidewalls. The floor of the reservoir is the floor of the storage tank or sewer line flush chamber in which the reservoir is installed. The ingress-egress port is positioned in one of the sidewalls along the bottom edge thereof. The reservoir opens to the sewer line flush chamber or storage tank through the ingress-egress port. The opening height of the port is about 2 to 4 in. higher than the historical height of the sediment-solid layer. The air intake conduit extends from an upper opening in the reservoir to a lower opening along a sidewall, other than the sidewall with the ingress-egress port. The air intake conduit may be in the form of a rectangular duct defined by a partition wall or in the form of an air intake tube connected to the reservoir at the upper opening by a tee joint. The lower opening is sized to be about 30% of the size of the ingress-egress port. The lower opening is about 5 to 8 cm (2 to 3 in.) higher than the top of the ingress-egress port.

In use during a storm, when the CSO storage tank or sewer line flush chamber downstream of the reservoir is filling up with W WF during a storm, the flow enters the reservoir through the ingress-egress port in the reservoir. As the liquid level rises in the reservoir, positive pressure automatically opens the air release valve allowing air to purge from the reservoir. When the reservoir is full, the air release valve automatically closes. During draining of the sewer or storage tank (e.g., after a storm), a vacuum is created in the air space of the reservoir that holds the liquid up in the reservoir. When liquid in the sewer or storage tank is drained to a predetermined level (below the elevation of the air intake conduit opening), air is drawn into the reservoir via the air intake conduit, breaking the vacuum inside the reservoir. Thus, water in the reservoir is quickly released through the ingress-egress port to the downstream storage tank or sewer, resuspending the settled sewer solids and transporting them to a sediment pit for final disposal.

The reservoir may be installed in an upstream end of the storage tank and/or sewer line with the ingress-egress port facing the downstream end of the storage tank or sewer line flush chamber. The ends of the reservoir may be mounted to the floor of the storage tank or sewer line flush chamber. When installed in the WWF storage tank, the volume of the reservoir will be based on the volume of the storage tank. For sewer line applications, the reservoir volume will depend on the size and the total length of the sewer line to be flushed.

Hydraulic Laboratory Testing of U.S. EPA Automatic Vacuum Flushing Device

A laboratory hydraulic flume was used to simulate a reach of sewer or storage tank. The flushing device was fabricated and installed at the head-end of the flume. The removed sediment was collected at the end of the flume and weighed. Water is held up by vacuum and is released upon dissipation of the vacuum in the vacuum-flushing device rather than through closing and opening of a mechanical gate in the gate-flushing device. The test results indicate that sediment removal efficiency of the vacuum-flushing device is close to the gate-flushing device (Guo et al., 2004).

Flushing Small Diameter Sewers

A field research program sponsored by EPA was conducted in the Dorchester area of Boston to determine the pollution reduction potential of flushing combined sewer laterals. It was concluded that small volume flushing of a 300 mm (12 in.) diameter pipe at a slope of 0.0049 would transport organics/nutrients and heavy metals sufficient distances (up to 305 m, 1000 ft) to make the option feasible and attractive (Pisano et al., 1979). The test segments were flushed three times each on five different days and the effectiveness (i.e., incremental removals at each downstream manhole by special sampling) of the flushes was empirically estimated based on the observed results in each field test. Table 23 presents the results of a single 1.4 m^3 (375 gal) manual flush to scour, entrain and transport materials within 30 cm to 46 cm (12 in. to 18 in.) pipes.

Table 23. Percent of pollutant removal by manual flush in small diameter sewers

Pollutant	Flushing Length 76 m (250 ft)	Flushing Length 213 m (700 ft)	Flushing Length 305 m (1000 ft)
Organic/Nutrient Deposits (BOD, TP, TN)	75–90%	65–75%	35–45%
Total Suspended Solids Deposits	75%	55–65%	18–25%

Flushing Small Diameter Sewers using a Dosing Siphon

A self-flushing tank, or "dosing siphon", designed to clean small diameter sewers has recently been developed in Germany as shown in Figure 4 (Pisano et al., 2001). The mechanism is placed in a manhole with an inlet from a water source such as a catch basin, sump pump, or from infiltrating groundwater. When the manhole is filled to a certain elevation, the mechanism creates a siphon and releases 0.76-1.13 m^3 (200-300 gal) of water in the manhole to the sewer. Since it is designed for smaller pipes, it works with low inlet flows, is less expensive to construct, and requires less space. It is designed for sewer diameters of 300 mm (12 in.) or less and can clean up to 183 m (600 ft) of sewer. The dosing siphon type mechanism is a patented device produced by Steinhardt (Pisano et al., 2001).

Figure 4. Dosing Siphon Top View and External Drum

The siphon mechanism resides in a solid stainless steel external drum open at the bottom to allow fluid within the manhole storage area to enter the device. Inside the external drum are guides bolted to the drum and attached to the discharge pipe connected to the sewer being flushed. Within this section is a stainless steel flexible hose having a solid connection to the sewer at the bottom and oversized section (larger diameter cup) at the top. On rising water level the flexible hose rises within the drum due to buoyancy force on the cup at the top of the hose. At a certain level the hose cannot extend any further and is now at maximum elevation. As the water level continues to rise and then spills over the fixed weir causing an unbalanced force on the top-side of the ring. At that point the hose collapses inducing the siphon effect, thus rapidly draining the contents of the manhole out the discharge pipe connected to the sewer. The effective volume of the flush equals the product of the height of the flexible hose and the effective cross section of the manhole.

Tests and Observations of Dosing Siphon

Tests were conducted with the dosing siphon at Cambridge, Massachusetts by the Montgomery Watson Harza project team on June 8, 15, and 21, 2001 (Pisano et al., 2001). Pertinent dimensions of the 25 cm (10 in.) vitrified clay pipe (VCP) segment 82 m (270 ft) test segment, upstream and downstream manholes. The flushing volume for each test was generated by filling the upstream manhole from a nearby fire hydrant. Seven repetitive flushing experiments were conducted on each day. Dye was introduced into the flushing waters to note time of arrival of the flushing wave. Peak velocity was then computed. Sediment characteristics were noted at the end of each flush. Base flow in the 25-cm (10 in.) segment averaged about 5 cm (2 in.). Volume of flush equaled 0.78 m^3 (207 gal) and peak velocities averaged about 1.1 m/s (3.6 ft/s).

Pre-flush and post-flush experiment sediment scrapings within the downstream manhole were performed on June 15 and June 21. All material within a portion of the downstream manhole was removed before the seven experiments were conducted. After all tests were performed the same area of the manhole was again scrapped. The following describes an assessment of the results:

Dosing Siphon Testing and Sediment Scraping Results at Museum Street, June 15, 2001

The second round of dosing siphon flush tests was conducted on June 15. The test program consisted of repeatedly filling with hydrant water end-of-the-line manhole having the dosing siphon directly connected into the test segment. A fill volume of approximately 0.76 m^3 (200 gal) generated a flush wave with a peak velocity noted 82 m (270 ft) at the downstream manhole of 1.1 m/s (3.6 ft/s). The experiment was repeated seven times. Sediment depths and the nature of sediments in the downstream manhole were visually noted after each flush.

Before starting the flush sequence, a sediment scraping was performed in the downstream manhole from a predetermined portion of the manhole base and placed in a container. The area was scrapped to the invert. After the seven experiments were performed, residual sediments in the downstream manhole were again scraped in exactly the same manner and placed in second container. These samples were retained for visual inspection and assessment. The following results are noted below.

- Approximately 300 g were collected in the pre-flush sample and about 900 g collected in the post-flush sample.
- There were 5 stones retained on the # 4 sieve, ranging from 0.64 cm to 1.25 cm (¼ in. to ½ in.) in the pre-flush sample.
- There were 31 stones well retained on the # 4 sieve, ranging from 0.64 cm to 1.9 cm (¼ in. to ¾ in.) in the post-flush sample.

The stones were removed and the remaining portions of each sample were visually inspected to approximate fractions of the residual mass per sieve size with the results presented in Table 24.

Table 24. Approximate fractions of residual mass per sieve size (after rocks removed)

Sieve Size Range	Pre-Flush Sample	Post-Flush Sample
> #10 and < #4	10%	30%
> #50 and < #10	10%	20%
> #200 and < #50	5%	20%
Organic Materials	75%	30%

Large grain sand and small gravel are typically retained by the #10 sieve. Material in excess of 0.64 cm (¼ in.) is retained on the #4 sieve. Medium grain sand is typically noted as #50 sieve, and very fine sand (i.e., "sugar sand" found on most Florida beaches) is typically captured by the #200 sieve.

Subsequent to the above observations, the collected rock was then carefully washed. All stones pre-flush and post-flush were crushed granite and evidently had been inadvertently discharged into the upstream recently upgraded manhole.

Dosing Siphon Testing and Sediment Scraping Results at Museum Street, June 21, 2001
The third round of dosing siphon flush tests was conducted on June 21. Procedural details were the same as the round two experiments. A fill volume of approximately 0.76 m^3 (200 gal) triggered the device sending flush water having a peak velocity noted 82 m (270 ft) downstream of 1.1 m/s (3.6 ft/s). The experiment was repeated seven times. Sediment depths and the nature of sediments in the downstream manhole were visually noted after each flush.

Before starting the flush sequence a sediment scrapping was performed in the downstream manhole from a predetermined portion of the manhole base and placed in a container. The area was scrapped to pipe invert. After the seven experiments were performed residual sediments in the downstream manhole were again scrapped in exactly the same manner and placed in second container. These samples were then visually inspected.

In the morning of June 22, the two samples were placed in two long plastic garden trays and hand spread for visual inspection and assessment. The following results are noted below:

- Approximately 500 g were collected in the pre-flush sample and about 1000 g were collected in the post-flush sample.

- There were 20 stones in excess of #4 sieve, ranging from 0.64 cm to 1.25 cm (¼ in. to ½ in.) in the pre-flush sample.

- There were 38 stones well in excess of #4 sieve, ranging from 0.64 cm to 1.9 cm (¼ in. to 3 in.) in the post-flush sample.

The stones were removed and the remaining portions of each sample were visually inspected to approximate fractions of the residual mass per sieve size with the results presented in Table 25.

Table 25. Approximate fractions of residual mass per sieve size (after rocks removed)

Sieve Size Range	Pre-flush Sample	Post-flush Sample
> #10 and < #4	10%	25%
> #50 and < #10	15%	25%
> #70 and < #50	30%	30%
> #200 and < #50	20%	10%
Organic Materials	25%	10%

The #70 sieve gradation for the large amount of small grain sand was added to the observations. The post-flush sample was far grittier than the pre-flush sample over the entire range. The large oblong rock was a piece of concrete that had been attached in the sediment bed for a long period as it was discolored and corroded.

Conclusions from Testing
Pisano et al. (2001) concluded that the dosing flushing scheme was capable of transporting large inorganic dense aggregate by combination of probably bed load movement and perhaps saltation (rising and falling, i.e., bouncing within the pipe segment). The earlier field research experiments conducted in the 1970s (Pisano et al. 1979)

would not have anticipated such a favorable result. It is probable that such favorable transport conditions have resulted from repeated flushing in short period of time precluding “stickiness” conditions. Since the dosing siphon device is meant to be filled either by infiltration or inflow mechanisms, repeated operation in a short time period is a probable design condition.

The other point worth noting is that the residual materials after flushing were more inorganic in nature which is important from “first-flush” and odor and corrosion prevention perspective. The results although preliminary and the measures of performance admittedly crude are encouraging.